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ON DIRECT CP VIOLATION IN $B \to \overset{(-)}{D^0} K\ \pi$'s vs. $\bar{B} \to \overset{(-)}{D^0} \bar{K}\ \pi$'s DECAYS*

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ABSTRACT

We discuss a class of decay modes for charged as well as neutral B mesons where direct CP violation could produce asymmetries of order few percent. Even an asymmetry as large as 10% is conceivable though admittedly optimistic. Two essential ingredients for such an asymmetry are the presence of the $V(ub)$ coupling and the intervention of nontrivial final state interactions; these two elements are also at the origin of large numerical uncertainties in the predictions. The third essential ingredient is the observation that D^0 and $\bar{D}^0$ mesons cannot be distinguished as a matter of principle if they decay into K_S+ pions. Such asymmetries can be searched for equally well on and off the $\Upsilon(4S)$ resonance.

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DEDICATION

We dedicate this paper to Abraham Pais on the occasion of his 70th birthday. Throughout our collaboration we have attempted to follow his taste in physics and we have aimed for the physics standards set by him. His interest in our work and his encouragements have served as a back bone of our collaboration while his frank and critical comments have kept us on course. We wish him a happy birthday and ask for his continuing support.

I.I.B. and A.I.S., May 19, 1988

I. Introduction

Searching for CP violation represents the ultimate task in beauty decays. Awesome experimental challenges have to be faced when tackling this task — yet the gain in knowledge and understanding that is expected justifies a major, dedicated effort.

On the theoretical side there exists a fairly exhaustive discussion of the general concepts that are involved here; basic search scenarios have been described in particular for CP asymmetries in the decays of neutral B mesons.[1] Let us just emphasize that many of these asymmetries can be predicted without too much uncertainty due to unknown strong interaction effects. Charged B decays on the other hand can exhibit CP asymmetries only if ***nontrivial final state interactions*** (hereafter referred to as *FSI*) intervene in an appropriate way. Accordingly, all predictions on the size of such CP asymmetries suffer from large theoretical uncertainties.

At present, we do not know how to reduce these uncertainties in a significant way. Nevertheless, it makes eminent sense to search for such asymmetries in a dedicated fashion. A positive signal would not immediately lead to a *quantitative* theoretical (in contrast to phenomenological) interpretation — yet for now this seems of secondary importance.

In this note we want to present a detailed discussion of a special type of charged as well as neutral B decays where

- CP asymmetries of up to 10% or so could conceivably emerge,
- searches can be performed in the reaction $\Upsilon(4S) \to B\bar{B}$ and
- semi-inclusive studies appear promising.

We will keep the discussion rather general to elucidate the underlying concepts and to illustrate how future experimental and theoretical information can help to decrease the numerical uncertainties.

II. The Class of Decays

When two different amplitudes contribute to the decay of a beauty hadron B or $\bar{B}$ into a final state f or $\bar{f}$ respectively, one writes down for the amplitude describing $\bar{B} \to \bar{f}$

$$\begin{aligned} \bar{A} \equiv \langle \bar{f} | \mathcal{L}(\Delta B = 1) | \bar{B} \rangle &= \langle \bar{f} | \mathcal{L}_1 | \bar{B} \rangle + \langle \bar{f} | \mathcal{L}_2 | \bar{B} \rangle \\ &= g_1 M_1 e^{i\alpha_1} + g_2 M_2 e^{i\alpha_2} \end{aligned} \quad . \tag{1}$$

M_1, M_2 denote the matrix elements for the two different weak transition operators $\mathcal{L}_1, \mathcal{L}_2$ with the KM parameters g_1, g_2 and the strong phase shifts α_1, α_2 factored out. The amplitude for the CP conjugate channel $B \to f$ then reads

$$A \equiv \langle f | \mathcal{L}(\Delta B = 1) | B \rangle = g_1^* M_1 e^{i\alpha_1} + g_2^* M_2 e^{i\alpha_2} \quad . \tag{2}$$

Comparing (1) and (2) one obtains[2]

$$\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f) \propto \ \mathrm{Im}\, g_1^* g_2 \sin(\alpha_1 - \alpha_2) M_1 M_2 \quad . \tag{3}$$

The specific reactions we will analyze are

$$\bar{B} \begin{array}{l} \nearrow D^0 \ K^- \ \pi's \searrow \\ \searrow \bar{D}^0 \ K^- \ \pi's \nearrow \end{array} (K_S \pi's)^0_D \ K^- \ \pi's \quad , \tag{4}$$

$$B \begin{array}{l} \nearrow \bar{D}^0 \ K^+ \ \pi's \searrow \\ \searrow D^0 \ K^+ \ \pi's \nearrow \end{array} (K_S \pi's)^0_D \ K^+ \ \pi's \quad . \tag{5}$$

A few general remarks are in order here:

(i) The flavor of the decaying meson — i.e., $\bar{B} = (b\bar{q})$ or $B = (\bar{b}q)$ — is revealed by the *charged* kaon. Thus no additional flavor tagging is required, i.e., these decays are flavor specific or "self-tagging."

(*ii*) $K^0 - \bar{K}^0$ mixing which generates the K_S is *essential* for making such a CP asymmetry observable. Otherwise, the intermediate D^0 or $\bar{D}^0$ states would be distinguishable and the necessary coherence between the two amplitudes lost: for the D^0 leads to a $\bar{K}^0$ or K^- whereas the $\bar{D}^0$ go to a K^0 or K^+ (in Cabibbo allowed decays).

(*iii*) The D^0K^- system carries pure isospin $(I, I_3) = (1, -1)$ and no nontrivial rescattering can occur, i.e., $D^0K^- \rightarrow D^0K^-$ only. The $\bar{D}^0K^-$ system, on the other hand, contains both $(I, I_3) = (1, 0)$ and $(0, 0)$ configurations. Accordingly, nontrivial rescattering can occur, i.e.,

$$\bar{D}^0K^- \begin{array}{l} \nearrow \bar{D}^0K^- \\ \searrow D_s^- \pi^0/\eta \end{array} .$$

Therefore, the FSI are bound to be different in the two cases. *This should introduce a sizeable difference in the phase shifts α_1 and α_2.*

These rather general statements will be analyzed in a more detailed and specific way by using a quark level description.

III. Quark Level Description

Figures 1(a) and (b) show the quark level diagrams for $B^- \rightarrow D^0K^-\pi's \rightarrow K_SK^- + \pi's$ and for $B^- \rightarrow \bar{D}^0K^-\pi's \rightarrow K_SK^- + \pi's$, respectively. It is exactly due to $K^0 - \bar{K}^0$ mixing that $\bar{K}^0 = (\bar{d}s)$ and $K^0 = (d\bar{s})$ cannot be distinguished and neither can those D^0 and $\bar{D}^0$ that decay into them. It should be noted that D^{0*} production can be included since $D^{0*}/\bar{D}^{0*}$ decay into a $D^0/\bar{D}^0$ plus a π^0 or γ. For K^* resonances the situation is different since the decays $\bar{K}^{0*} \rightarrow K^-\pi^+$ and $K^{-*} \rightarrow \bar{K}^0\pi^-$ reveal their flavor.

The corresponding diagram for B^0 decays produces a $(s\bar{d})$ cluster together with the D^0 or $\bar{D}^0$. Such a neutral cluster is *flavour specific* if it hadronizes like $\bar{K}^{0*} \rightarrow K^-\pi^+$ or $K^- + \pi$'s in general.

We also realize that we are dealing with KM suppressed transitions: Cabibbo suppression in one amplitude, $V(ub)/V(cb)$ in the other. This way one is sensitive to the undiluted complex phase in $V(ub)$ [relative to $V(cb)$]:

$$A(B^- \to D^0 K^- \pi' s) \propto V(cb)V^*(us) = A\lambda^3 \tag{6}$$

$$A(B^- \to \bar{D}^0 K^- \pi' s) \propto V(ub)V^*(cs) = A\lambda^3(\rho - i\eta) \tag{7}$$

in the Wolfenstein representation of the KM matrix. Data on semileptonic and baryonic B decays suggest

$$\sqrt{\rho^2 + \eta^2} \sim \mathcal{O}(1) \quad .$$

The two amplitudes of Eq. (6) and (7) are then roughly equal in size — a necessary condition for sizeable interference effects and thus for these CP asymmetries. Yet looking at the flow of momenta through the diagrams in Fig. 1 one might conclude that the momenta of the corresponding $q'\bar{q}$ clusters are ill-matched; this would decrease the coherence between the two amplitudes.

A more detailed analysis is required to deal with the issue of coherence, and we undertake to present such an analysis in the following.

The Lagrangian driving these B decays contains four current-current operators whose relative weight depends on the KM parameters and on QCD renormalization effects:

$$\begin{aligned}\mathcal{L}(\Delta B = 1) \propto V(cb)V^*(us) &\left\{ \frac{c_+ + c_-}{2} (\bar{c}b)_L (\bar{s}u)_L + \frac{c_+ - c_-}{2} (\bar{s}b)_L (\bar{c}u)_L \right\} \\ + V(ub)V^*(cs) &\left\{ \frac{c_+ + c_-}{2} (\bar{u}b)_L (\bar{s}c)_L + \frac{c_+ - c_-}{2} (\bar{s}b)_L (\bar{u}c)_L \right\}\end{aligned} \tag{8}$$

The renormalization coefficients $c_\pm$ are computed perturbatively in QCD where one obtains[4]

$$c_+ \sim 0.82, \quad c_- \sim 1.5 \quad . \tag{9}$$

Thus, there are four current-current matrix elements that appear in the decay amplitude, namely $\langle D^0 K^- \pi' s | (\bar{c}b)_L (\bar{s}u)_L | \bar{B} \rangle$, $\langle D^0 K^- \pi' s | (\bar{s}b)_L (\bar{c}u)_L | \bar{B} \rangle$ and $\langle \bar{D}^0 K^- \pi' s | (\bar{u}b)_L (\bar{s}c)_L | \bar{B} \rangle$, $\langle \bar{D}^0 K^- \pi' s | (\bar{s}b)_L (\bar{u}c)_L | \bar{B} \rangle$.

The "spectator" quark for B^- mesons is $\bar{u}$; the structure of the first two matrix elements is therefore quite different from that of the last two. Figures 2 and 3 explicitly show this feature for the two-body decay modes. Accordingly, we write down

$$\langle D^0 K^- + n\pi | (\bar{c}b)_L (\bar{s}u)_L | B^- \rangle \equiv A^{(ch)}_{1,n} + \xi_1 A^{(ch)}_{2,n} \tag{10}$$

$$\langle D^0 K^- + n\pi | (\bar{s}b)_L (\bar{c}u)_L | B^- \rangle \equiv A^{(ch)}_{2,n} + \xi_2 A^{(ch)}_{1,n} \tag{11}$$

$$\langle \bar{D}^0 K^- + n\pi | (\bar{u}b)_L (\bar{s}c)_L | B^- \rangle \equiv \xi_1 \bar{A}^{(ch)}_{2,n} \tag{12}$$

$$\langle \bar{D}^0 K^- + n\pi | (\bar{s}b)_L (\bar{u}c)_L | B^- \rangle \equiv \bar{A}^{(ch)}_{2,n} \quad . \tag{13}$$

The factor $\xi_1[\xi_2]$ represents the probability that the $(c\bar{u})[(u\bar{c})]$ pair in Fig. 2(b) [3(b)] which *a priori* is uncorrelated in color will produce the color singlet $D^0[\bar{D}^0]$. This somewhat cumbersome looking notation is chosen as to be consistent with the definitions by Stech et. al.[3] when one restricts oneself to two-body decay modes. The subscript n refers to the number of pions in the final state.

Somewhat simpler expressions appear for neutral B decays:

$$\langle D^0 K^- + n\pi | (\bar{c}b)_L (\bar{s}u)_L | \bar{B}_d \rangle \equiv \xi_1 A^{(neut)}_{2,n} \tag{14}$$

$$\langle D^0 K^- + n\pi | (\bar{s}b)_L (\bar{c}u)_L | \bar{B}_d \rangle \equiv A^{(neut)}_{2,n} \tag{15}$$

$$\langle \bar{D}^0 K^- + n\pi | (\bar{u}b)_L (\bar{s}c)_L | \bar{B}_d \rangle \equiv \xi_1 \bar{A}^{(neut)}_{2,n} \tag{16}$$

$$\langle \bar{D}^0 K^- + n\pi | (\bar{s}b)_L (\bar{u}c)_L | \bar{B}_d \rangle \equiv \bar{A}^{(neut)}_{2,n} \quad . \tag{17}$$

To separate out effects due to strong FSI from the matrix elements of quark operators between hadrons we set

$$A_{1,n}[A_{2,n}] = a_{1,n}[a_{2,n}]f_{K^- D^0 n\pi} \quad , \tag{18}$$

$$\bar{A}_{2,n} = \bar{a}_{2,n} f_{K^- \bar{D}^0 n\pi} \quad . \tag{19}$$

where the strong phases, absorption etc. are placed into the quantities $f_{D^0 K^- n\pi}$, $f_{\bar{D}^0 K^- n\pi}$. As mentioned before (and shown in Fig. 3) there are more inelastic channels for $K^- \bar{D}^0 n\pi$ than for $K^- D^0 n\pi$. The FSI factors should therefore be quite different. Defining

$$\frac{f_{K^- \bar{D}^0 n\pi}}{f_{K^- D^0 n\pi}} \equiv r_n e^{i\phi_n}$$

and dropping the explicit reference to *ch*arged or *neut*ral amplitudes, we obtain

$$A(B^- \to D^0/\bar{D}^0 K^- n\pi) \propto \{F_n + r_n e^{i\phi_n} \frac{V(ub)V^*(cs)}{V(cb)V^*(us)} \cdot \bar{F}_n\} \tag{20}$$

$$F_n = c_1(a_{1,n} + \xi_1 a_{2,n}) + c_2(a_{2,n} + \xi_2 a_{1,n}) \tag{21}$$

$$\bar{F}_n = (c_1 \xi_1 + c_2)\bar{a}_{2,n} \tag{22}$$

where $c_1 = \frac{1}{2}(c_+ + c_-), c_2 = \frac{1}{2}(c_+ - c_-)$. The general expression for the CP asymmetry then reads as follows:

$$\begin{gathered}\frac{\Gamma(B^- \to D^0/\bar{D}^0 K^- n\pi) - \Gamma(B^+ \to D^0/\bar{D}^0 K^+ n\pi)}{\Gamma(B^- \to D^0/\bar{D}^0 K^- n\pi) + \Gamma(B^+ \to D^0/\bar{D}^0 K^+ n\pi)} = \\ \frac{-2F_n \otimes \bar{F}_n r_n \sin\phi_n Im(KM)}{F_n^2 + r_n^2 |KM|^2 (\bar{F}_n)^2 + 2F_n \otimes \bar{F}_n r_n \cos\phi_n Re(KM)}\end{gathered} \tag{23}$$

where

$$KM = \frac{V(ub)V^*(cs)}{V(cb)V^*(us)} \simeq \rho - i\eta \tag{24}$$

The symbol "$\otimes$" in $F_n \otimes \bar{F}_n$ denotes the fact that a nontrivial integration over momenta is involved in the products of $a_{1,n}$ and $a_{2,n}$ with $\bar{a}_{2,n}$. We will come back to this point later on.

For neutral B decays one obtains different expressions as is evident from a comparison of (10-13) with (14-17):

$$A(\bar{B}_d \to D^0/\bar{D}^0 K^- + n\pi) \propto (c_1 \xi_{1,n} + c_2)(a_{2,n} + KM\ r_n e^{i\phi_n} \bar{a}_{2,n}) \tag{25}$$

$$\frac{\Gamma(\bar{B}_d \to D^0/\bar{D}^0 K^- n\pi) - \Gamma(B_d \to D^0/\bar{D}^0 K^+ n\pi)}{\Gamma(\bar{B}_d \to D^0/\bar{D}^0 K^- n\pi) + \Gamma(B_d \to D^0/\bar{D}^0 K^+ n\pi)} = \frac{-2a_{2,n} \otimes \bar{a}_{2,n} r_n \sin\phi_n Im(KM)}{a_{2,n}^2 + r_n^2 |KM|^2 (\bar{a}_{2,n})^2 + 2a_{2,n} \otimes \bar{a}_{2,n} r_n \cos\phi_n Re(KM)} \tag{26}$$

So far our results are quite general and applicable to any scenario of strong interactions. In order to obtain a more specific estimate on the expected size of the asymmetry we shall employ the factorization approximation for evaluating the matrix elements (ignoring FSI just for the moment)[3]:

$$a_{1,n}^{(ch)} \simeq \langle D^0 + \pi's|(\bar{c}b)_L|B^-\rangle\langle K^- + \pi's|(\bar{s}u)_L|0\rangle \simeq a_{1,n}^{(neut)} \tag{27}$$

$$a_{1,n}^{(neut)} \simeq \langle D^0 + \pi's|(\bar{c}b)_L|\bar{B}_d\rangle\langle K^- + \pi's|(\bar{s}u)_L|0\rangle \tag{28}$$

$$a_{2,n}^{(ch)} \simeq \langle K^- + \pi's|(\bar{s}b)_L|B^-\rangle\langle D^0 + \pi's|(\bar{c}u)_L|0\rangle \simeq a_{2,n}^{(neut)} \tag{29}$$

$$\bar{a}_{2,n}^{(ch)} \simeq \langle K^- + \pi's|(\bar{s}b)_L|B^-\rangle\langle D^0 + \pi's|(\bar{u}c)_L|0\rangle \simeq \bar{a}_{2,n} \tag{30}$$

In this approximation we also have

$$a_{2,n} = \bar{a}_{2,n} \quad , \tag{31}$$

$$\xi_1 = \xi_2 \equiv \xi \quad . \tag{32}$$

A comprehensive analysis of D and B decays strongly prefers [3]

$$\xi \simeq 0 \quad , \tag{33}$$

at least for two-body decay modes.

For two-body decay modes,

$$B^- \to D^0/\bar{D}^0/D^{0*}/\bar{D}^{0*} + K^-/K^{-*}$$

$$\bar{B} \to D^0/\bar{D}^0/D^{0*}/\bar{D}^{0*} + \bar{K}^{0*}, \quad \bar{K}^{0*} \to K^-\pi^+$$

we expect furthermore,

$$a_1 \simeq a_2 = \bar{a}_2 \quad . \tag{34}$$

With Eqs. (29) and (30), the lengthy expressions in Eq. (21) and (23) simplify tremendously

$$\begin{aligned}&\frac{\Gamma(B^- \to D^{0(*)}/\bar{D}^{0(*)} + K^-) - \Gamma(B^+ \to D^{0(*)}/\bar{D}^{0(*)} + K^+)}{\Gamma(B^- \to D^{0(*)}/\bar{D}^{0(*)} + K^-) + \Gamma(B^+ \to D^{0(*)}/\bar{D}^{0(*)} + K^+)} \\ &\simeq -\frac{c_+ - c_-}{c_+ + (c_+ - c_-)\rho r_0 \cos\phi_0} \eta r_0 \sin\phi_0 \sim 0.8\ \eta r_0 \sin\phi_0\end{aligned} \tag{35}$$

$$\begin{aligned}&\frac{\Gamma(\bar{B}_d \to D^{0(*)}/\bar{D}^{0(*)} + \bar{K}^{0*}) - \Gamma(B_d \to D^{0(*)}/\bar{D}^{0(*)} + K^{0*})}{\Gamma(\bar{B}_d \to D^{0(*)}/\bar{D}^{0(*)} + \bar{K}^{0*}) + \Gamma(B_d \to D^{0(*)}/\bar{D}^{0(*)} + K^{0*})} \\ &\simeq \frac{2\eta r_0 \sin\phi_0}{1 + r_0^2(\rho^2 + \eta^2) + 2\rho r_0 \cos\phi_0}\end{aligned} \tag{36}$$

where we have used the Wolfenstein representation of the KM matrix.

Extracting η from $K_L \to \pi\pi$ decays, one obtains

$$\eta \sim 0.1 - 0.4 \quad , \tag{37}$$

where major sources of the uncertainty are the unknown sizes of the top mass and of the hadronic matrix elements.

Nothing definite can be said about $\sin\phi$ other than repeating that there is no reason for it to be particularly small. Thus we will use as a guestimate,

$$\sin\phi \sim 0.1 - 1 \quad , \tag{38}$$

and, therefore,

$$\frac{\Gamma(B^- \to D^0/\bar{D}^0 + K^-) - \Gamma(B^+ \to D^0/\bar{D}^0 + K^+)}{\Gamma(B^- \to D^0/\bar{D}^0 + K^-) + \Gamma(B^+ \to D^0/\bar{D}^0 + K^+)} \sim 0.01 - 0.32 \tag{39}$$

$$\frac{\Gamma(\bar{B}_d \to D^0/\bar{D}^0 + \bar{K}^{0*}) - \Gamma(B_d \to D^0/\bar{D}^0 + K^{0*})}{\Gamma(\bar{B}_d \to D^0/\bar{D}^0 + \bar{K}^{0*}) + \Gamma(B_d \to D^0/\bar{D}^0 + K^{0*})} \sim 0.01 - 0.4 \tag{40}$$

i.e., an asymmetry of up to 30% is conceivable, though it might be as small as of order 1%. The pseudoscalar states D^0 and $K^\pm$ can be replaced by their vector partners D^{0*} and $K^{\pm *}$.

One should keep in mind that the choices stated in Eqs. (31-34) are not sacrosanct:

- The choice $\xi = 0$ gives a very decent overall fit to nonleptonic, two-body decays of D and B mesons. Yet this "universal" value represents an average and it is quite conceivable if not even likely that different decay channels are ruled by somewhat different values of ξ.
- The size of the matrix elements a_1 and a_2 depends on the meson decay constant, f_D or f_K, and on the formfactors describing the $B \to D$ and $B \to K$ transitions. These formfactors are represented by single pole terms and do depend on the position of the pole and its residue. Using the model of Ref. 3 one finds indeed $a_1 \simeq a_2$. Yet this equality could also be violated by a factor of two.

So far we have discussed the two-body decay modes $B^\pm \to D^{0(*)}/\bar{D}^{0(*)}K^{\pm(*)}$ and $\bar{B}_d \to D^{0(*)}/\bar{D}^{0(*)}\bar{K}^{0*}$ where their trivial kinematics enforces coherence between the various underlying quark diagrams. For an inclusive process, inspection of Fig. 4 leads to the conclusion that there is not much overlap in momentum space between the final states represented by a_1 and a_2. Accordingly, we find

$$
\begin{aligned}
&\frac{\Gamma(B^- \to D^0/\bar{D}^0 + K^- n\pi) - \Gamma(B^+ \to D^0/\bar{D}^0 + K^+ n\pi)}{\Gamma(B^- \to D^0/\bar{D}^0 + K^- n\pi) + \Gamma(B^+ \to D^0/\bar{D}^0 + K^+ n\pi)} \\
&= \frac{-2c_2^2 r_n \sin\phi_n}{c_1^2\left(\frac{a_1}{a_2}\right)^2 + c_2^2 + r_n^2(\eta^2+\rho^2)c_2^2 + 2c_2^2\rho r_n \cos\phi_n} \qquad (41) \\
&\sim 0.15 \sin\phi_n \eta \sim \text{few} \times 10^{-3} - 0.07
\end{aligned}
$$

The factor of five reduction in Eq. (35) relative to Eq. (34) reflects the substantially decreased coherence in multi-body versus two-body decay modes which we have implemented by setting $a_{1,n} \otimes a_{2,n} = 0$.

For B_d decays one does not expect a similar suppression in inclusive modes since only a_2 amplitudes contribute there. A reduction of the asymmetry could however occur if $\sin\phi_n$ changes sign for different n.

IV. Expected Statistics

The inclusive branching ratios into D^0 and D^+ have been measured by two groups where an average over $\bar{B}^0$ and B^- decays was taken:

$$
\mathrm{BR}(\bar{B} \to D^0 X) = \begin{cases} 0.52 \pm 0.07 \pm 0.07 & \text{CLEO} \\ 0.63 \pm 0.08 \pm 0.08 & \text{ARGUS} \end{cases} \qquad (42)
$$

$$
\mathrm{BR}(\bar{B} \to D^+ X) = \begin{cases} 0.22 \pm 0.05 \pm 0.03 & \text{CLEO} \\ 0.25 \pm 0.05 \pm 0.04 & \text{ARGUS} \end{cases} \qquad (43)
$$

This preponderance of D^0 over D^+ is easily understood by including D^* production: for whereas a D^{0*} always decays to a D^0 plus a π^0 or γ, a D^{+*} decays to D^+ plus π^0 or γ only half the time. Assuming a 3:1 ratio for $D^* : D$ production as suggested by spin counting one expects a factor of 2.2 between the D^0 and D^+ yields.

In B^- decays one actually expects mainly D^0 and D^{0*}, but very few D^+ or D^{+*}:

$$\mathrm{BR}(B^- \to D^0 + X) \sim 0.6 \tag{44}$$

The requirement to have another charged K introduces Cabibbo suppression; therefore, one estimates

$$\mathrm{BR}(B^- \to D^0 K^- + \pi' s) \sim 2 - 3\% \quad . \tag{45}$$

The neutral D meson has to be found in a mode $K_S + \pi' s$ like $\overset{(-)}{D^0} \to K_S \pi^0, K_S \rho^0, K_S \omega, K_S \eta, K_S \eta', K_S \pi^+ \pi^-$ (where $K_S \pi^+ \pi^- \neq K^{*-} \pi^+$). Assuming that 5% of the $D^0/\bar{D}^0$ decays can be found in these modes we arrive at

$$\mathrm{BR}(B^- \to D^0/\bar{D}^0 K^- + \pi' s \to (K_S \pi' s)_D K^- + \pi' s) \sim 10^{-3} \quad . \tag{46}$$

With a sample of $10^6 B^\pm$ one would then have 1000 events of this type which would allow to search for a 10% CP asymmetry on the three σ level.

At the other end, for two-body processes one guestimates

$$\mathrm{BR}(B^- \to D^0 + K^-/K^{-*}) \sim 10^{-3} \quad . \tag{47}$$

If 10% of the neutral D decays are identified in $K_S + \pi' s$ final states, then $10^6 B^\pm$ produce a sample of 100 events. This would allow to search for a 30% asymmetry on the three σ level.

The numbers work out somewhat differently for B_d decays. Expecting $BR(\bar{B}_d \to D^0 + X) \sim 0.1$ one estimates

$$BR(\bar{B}_d \to D^0 K^- + \pi' s) \sim 5 \cdot 10^{-3} \tag{48}$$

to arrive at

$$BR(\bar{B}_d \to D^0 K^- + \pi' s \to (K_S \pi' s)_D K^- + \pi' s) \sim 2.5 \cdot 10^{-4} \tag{49}$$

10^6 B_d would then yield 250 of these decays. With those one could search for a 20 % asymmetry on the three σ level. For the exclusive mode $\bar{B}_d \to D^0/\bar{D}^{0(*)} \bar{K}^{0*}$

one guestimates a branching ratio of $\sim 10^{-4}$, i.e. presumably too small for a meaningful search.

Obviously no allowance was made for less than perfect detection efficiencies etc. in our order of magnitude guestimates.

V. Summary

Our preceding discussion presumably made it quite clear that one cannot give firm and precise predictions on these "direct" CP asymmetries. On the other hand, it is conceivable that two-body decays like

$$B^{\pm} \rightarrow D^0/\bar{D}^0/D^{0*}/\bar{D}^{0*} + K^{\pm}/K^{\pm *}$$

$$\bar{B}_d \rightarrow D^0/\bar{D}^0/D^{0*}/\bar{D}^{0*} + \bar{K}^{0*}$$

could exhibit large CP asymmetries of 10 or 20% (or even more under extremely favorable conditions). The price one pays is the tiny *effective* branching of order 10^{-4} for $B^{\pm}$ or even 10^{-5} for $\bar{B}_d$ decays which is due to three concurrent reasons:

(*i*) we are dealing with an exclusive two-body decay mode

(*ii*) which is Cabibbo suppressed and

(*iii*) we can employ only $D^0 \rightarrow K_S + \pi's$ decays.

Alternatively – to gain in statistics – one can analyze semi-inclusive $B^{\pm}$ decays

$$B^{\pm} \rightarrow D^0/\bar{D}^0/D^{0*}/\bar{D}^{0*} + K^{\pm}/K^{\pm *} + \pi's$$

$$\bar{B}_d \rightarrow D^0/\bar{D}^0/D^{0*}/\bar{D}^{0*} + K^- + \pi's$$

The CP asymmetry in $B^{\pm}$ decays is not expected to exceed the few percent level due to a partial loss of coherence; in B_d decays on the other hand one could still find CP asymmetries of up to 10-20 % (with luck)!

With a sample of $10^6 - 10^7$ B mesons one might have a fighting chance to see these effects of direct CP violation if the asymmetries are close to their maximally allowed values. Not seeing an effect on this level would not teach us a great deal; yet seeing it would represent a very major discovery even in the absence of precise predictions.

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Figure Captions

Fig.1: Quark level diagrams for $B^- \to D^0/D^{0*}/\bar{D}^0/\bar{D}^{0*} + K\pi's$.

Fig.2: Quark level diagrams for $B^- \to D^0K^-$ via $b \to c$.

Fig.3: Quark level diagrams for $B^- \to D_s^-\pi^0/\eta,\quad \bar{D}^0K^-$ via $b \to u$.

Fig.4: Quark level diagrams for B^- decays with a multibody final state.

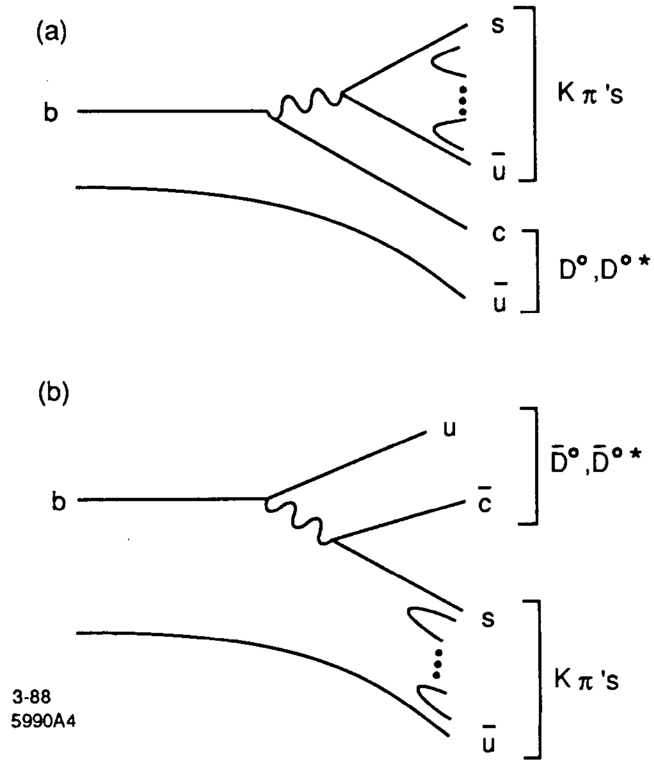

Fig. 1

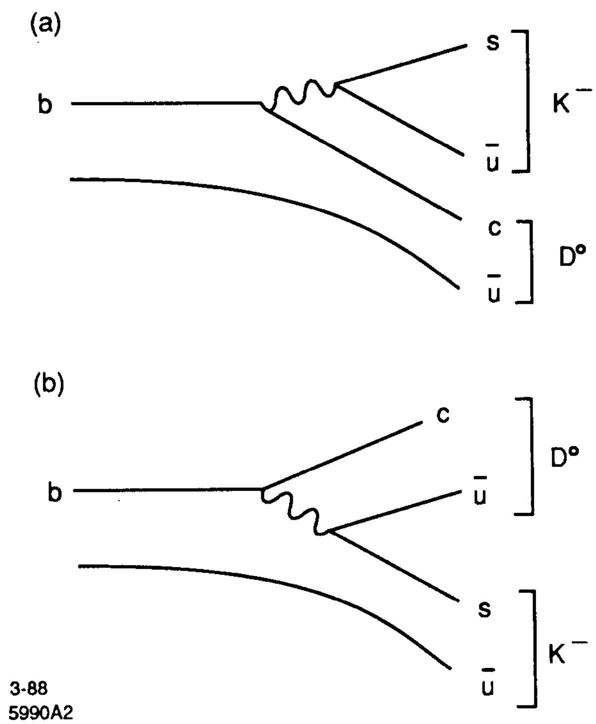

Fig. 2

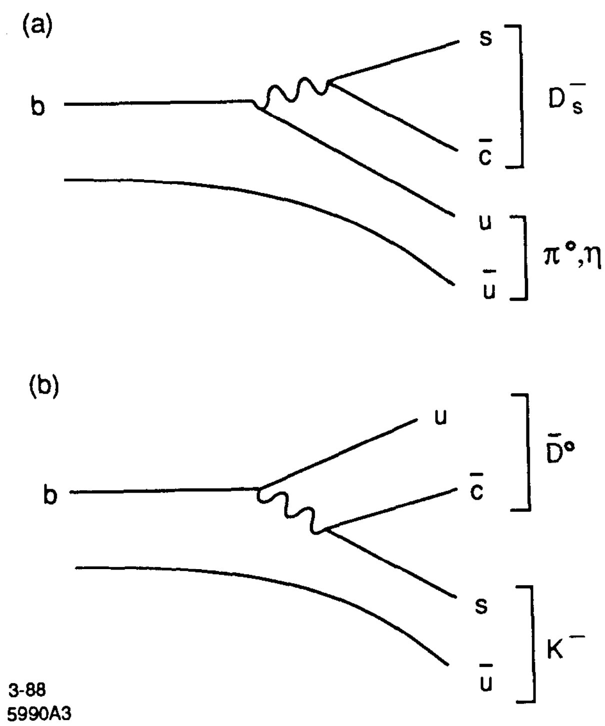
(a)
b
s
$\bar{c}$
D_s^-
u
$\bar{u}$
π°,η
(b)
b
u
$\bar{c}$
$\bar{D}^\circ$
s
$\bar{u}$
K^-
3-88
5990A3

Fig. 3

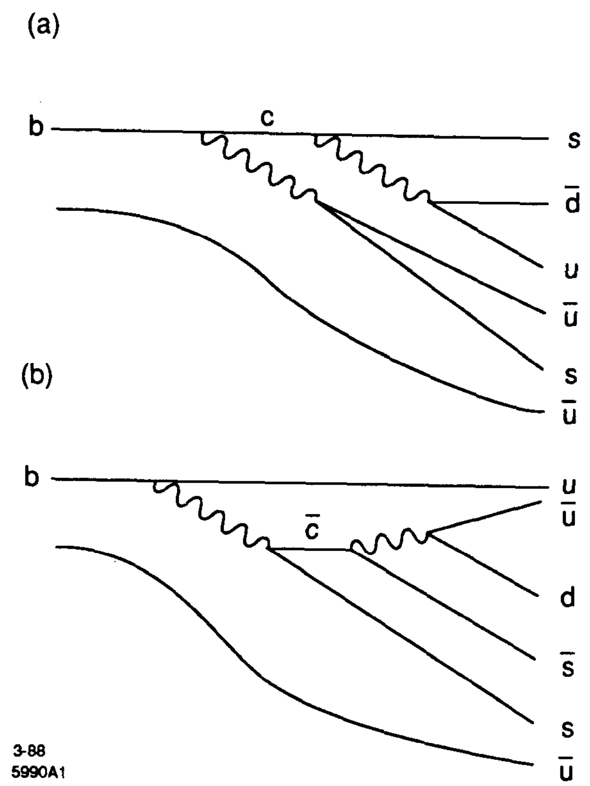

Fig. 4